

Development of Evaluation Procedures for Local Exhaust Ventilation for United States Postal Service Mail-Processing Equipment

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Researchers from the National Institute for Occupational Safety and Health (NIOSH) have conducted several evaluations of local exhaust ventilation (LEV) systems for the United States Postal Service (USPS) since autumn 2001 when (a) terrorist(s) employed the mail system for acts of bioterrorism. As a part of the USPS 2002 Emergency Preparedness Plan, the development and installation of LEV onto USPS mail-processing equipment can reduce future exposures to operators from potentially hazardous contaminants, such as anthrax, which might be emitted during the processing of mail. This article describes how NIOSH field testing led to the development of recommended testing procedures for evaluations of LEV capture efficiency for mail-processing equipment, including tracer gas measurements, smoke release observations, air velocity measurements, and decay-rate testing under access hoods.

Keywords anthrax, bioterrorism, effectiveness testing, local exhaust ventilation (LEV), smoke release, tracer gas (TG)

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INTRODUCTION

In September and October 2001, the mail distribution system of the United States Postal Service (USPS) was used by (an) unknown terrorist(s) to distribute *B. Anthracis*-laced letters. As a direct result of these attacks, a total of 22 cases of anthrax were identified; 11 were confirmed as inhalational anthrax, and 11 (7 confirmed and 4 suspected) were cutaneous.⁽¹⁾ Additionally, the Brentwood Mail Facility in Washington, D.C., and the Hamilton Township Facility in New Jersey were closed because of these attacks. Accordingly, the USPS instituted an Emergency Preparedness Plan to ameliorate the effects of any future attacks. Measures to be implemented focused on (1) redesign of collection boxes for risk reduction and detection, (2) development of technology and procedures to reduce the

volume of anonymous mail, (3) further deployment of vacuum and filtration technology on automated sorting equipment, (4) detection by mass spectrometry, and (5) various technologies to aid investigators in finding the perpetrator(s) of the fall 2001 attacks and in deterring further attempts at placing biohazards in the mail.⁽²⁾

In November 2001, the National Institute for Occupational Safety and Health (NIOSH) was asked for technical assistance in evaluating the ventilation and filtration technology, or local exhaust ventilation (LEV), developed by outside vendors for the USPS as a part of its Emergency Preparedness Plan. This document details the methodology employed to determine LEV capture efficiency and characterizes the practical effectiveness of these methods for field testing. (Evaluation of the filtration component of the LEV was evaluated separately by NIOSH and is not treated in this article.) Based on the results of these methods, a battery of tests is recommended for future evaluations of LEV capture efficiency for mail-processing equipment.

METHODS

NIOSH evaluations of the USPS centered on LEV for the Delivery Bar Code Sorter (DBCS); the Automated Flats Sorting Machine 100 (AFSM 100); the Advanced Facer Cancellor System (AFCS); and the 010 Culling System, which is made up of the Dual Pass Rough Cull (DPRC) System and the Loose Mail Distribution System (LMDS). The methods for evaluating the LEV systems for USPS mail-processing equipment focused on six tests: (1) introduction of anthrax spore-sized particles into the controls for mail-processing equipment and subsequent measurements of particle count levels as an approximation of capture efficiency; (2) measurement of particle count levels during regular mail processing to approximate capture efficiency; (3) air velocity measurements at possible points of contaminant release (i.e., at locations of high mechanical agitation where workers spent the majority of their time); (4) estimation of LEV capture efficiency using the

tracer gas (TG) sulfur hexafluoride; (5) qualitative observations of LEV effectiveness during smoke release experiments; and (6) characterization of the contaminant decay rate under access covers by smoke release, TG, and particle count experiments. The following discussion of methods includes a description of each, as well as the LEV performance criteria for each method.

Particle Count Experiments with Particulate Release

Description

Experiments were made to simulate the release of anthrax into the DBCS and AFSM 100 by releasing particles into the machines. Introduction of these particles was accomplished by three different methods:

- At the DBCS, a bright orange, fluorescent powder (Day-Glo Color Corp., PN FT-15-N) was placed inside a standard business envelope, along with an 8½" × 11" sheet of copy paper, which was folded into thirds. The folded paper was used to create a pocket of air that would aid in the dispersal of the orange powder when the envelope was squeezed or impacted.
- At the AFSM 100, 3-micron (μm) monodisperse latex spheres were introduced into the work zone by a puff bulb, fitted with a check valve.
- At the AFSM 100, 3 μm monodisperse latex spheres were incorporated into the mail-processing stream by their placement in two 8½" × 11" sheets of copy paper, which were folded in thirds. One of these sheets was placed inside a standard business envelope, and the other in a 12" × 9½" manila envelope.

For these three types of particle-release experiments, the procedure was simply to compare control-off versus control-on particle count values at different locations. These data were collected at various workstations by several types of particle counters. This equipment included a hand-held particle counter (model 227; Met One, Inc., Grants Pass, Ore.), which uses optical scattering technology to estimate particle count; particle size analyzers (1100 series; Grimm Technologies, Inc., Douglasville, Ga.), which use optical scattering technology to measure particle concentration and estimate particle size; and an aerodynamic particle sizer spectrometer (model 3320; TSI, Inc., St. Paul, Minn.), which measures particle size distribution.

Performance Criteria

A specific LEV capture efficiency goal was required at locations where there was high mechanical agitation, where the contaminant was potentially released close to the worker's breathing zone, and where workers spent the majority of their time. Furthermore, specific target capture efficiency was required even at locations where there was relatively low mechanical agitation, and where workers spent little time.

Regular Mail Experiments

Description

Particle count experiments were also made with particulate generated by regular mail. The procedure for these experiments was simply to compare control-off versus control-on particle count values at different locations, during regular mail processing to estimate relative contaminant capture efficiency.

Data for these experiments were collected at various locations by handheld particle counters (model 227; Met One), particle size analyzers (model 1106; Grimm Technologies), and the Aerodynamic Particle Sizer[®] Spectrometer (model 3320; TSI).

Performance Criteria

Performance criteria for the LEV, based on regular mail experiments, were the same as those based on the above-mentioned particulate release experiments.

Air Velocity Measurements

Description

Velocity measurements were taken with an air velocity meter (VelociCalc[®]; TSI Inc., St. Paul, Minn.). Measurements were taken at exhaust inlets and at possible contaminant release points for various mail-processing equipment. At each measurement location, reported air velocities were an average of three values, taken at approximately 2-sec intervals, for a total measurement time of about 6 sec.

Performance Criteria

NIOSH-defined performance criteria regarding appropriate capture velocities were based on values recommended by the American Conference of Governmental Industrial Hygienists' (ACGIH[®]) *Industrial Ventilation Manual*.⁽³⁾ Accordingly, where potential contaminant was released at practically no velocity into quiet air, the recommended capture velocity was 100 feet per minute (fpm) minimum. However, where a potential contaminant was released at low velocity into moderately still air, the recommended capture velocity was 200 fpm.⁽⁴⁾

The above guidelines set forth in the *Industrial Ventilation Manual* are qualified by the statement that:

Exceptionally high air flow hoods . . . may require less air flow [sic] than would be indicated by the capture velocity values recommended for small hoods. This phenomenon may be ascribed to:

- *The presence of a large air mass moving into the hood.*
- *The fact that the contaminant is under the influence of the hood for a much longer time than is the case with small hoods.*
- *The fact that the large air flow rate affords considerable dilution . . .*⁽⁵⁾

Therefore, evaluation of ventilated areas that are influenced by a large air mass and yet experience capture velocities less than 100 fpm should use other measures of capture efficiency, such as smoke release observations and TG experiments.

However, the USPS performance criterion for contaminant capture velocity was set at a minimum of 100 fpm at all critical locations, regardless of any other considerations.

Tracer Gas Evaluations

Description

By releasing TG at a constant rate where contaminant control was desired, and by measuring the corresponding downstream TG concentration inside the exhaust duct, NIOSH measured control efficiency quantitatively. The first step was to release the TG inside the duct to find the concentration C100 corresponding to 100% capture; this was done before and after TG experiments were made. Then, when the TG was released at any point of interest, resulting in a concentration C in the duct, the capture efficiency at the release point was calculated as C/C100. For these experiments, the TG was 100% sulfur hexafluoride. The instrument used to detect the sulfur hexafluoride was the Specific Vapor Analyzer (Miran[®] 203; The Foxboro Company, Foxboro, Mass.).

Performance Criteria

The performance criteria of TG was the same as that determined for particle count experiments because both were based on percent capture efficiency at particular locations. In particular, a specific LEV capture efficiency goal was required at locations where there was high mechanical agitation, where the contaminant was potentially released close to the worker's breathing zone, and where workers spent the majority of their time. Furthermore, specific target capture efficiency was required even at locations where there was relatively low mechanical agitation and workers spent little time.

Smoke Release Observations

Description

Smoke, generated by a smoke generator (F-800 Mini Fogger; Chauvet[®], Hollywood, Fla.), was released into the intake zone of the machine at all locations where airflow was induced by the control. Special care was taken to observe the capture of smoke where a contaminant would quite likely be generated. Moreover, where needed, these observations were aided by a focused, high-intensity light source.

Performance Criteria

Qualitative observations determined how quickly and effectively the control captured smoke. For example, if the smoke was captured quickly and directly by the exhaust system, it indicated acceptable control design and performance. However, if the smoke was slow to be captured when released at a certain point or took a circuitous route to the exhaust inlet, the ventilation system design was judged as marginal or poorly located.

Contaminant Removal Rate Determination

Description

Clouds of monodisperse latex spheres, TG, and smoke were introduced inside the machines at various locations to enable

quantification of the dynamic behavior of the ventilation control system that operated under the access covers. Workers frequently were vulnerable to exposures in this area because they had to remove jammed mail.

- Particulate, made up of 3- μ m monodisperse latex spheres, was introduced under several maintenance access covers of the AFSM 100. The Aerodynamic Particle Sizer Spectrometer (TSI Inc.) was then positioned to record particle counts that ascertained the rate at which the contaminant was removed by the LEV.
- The DBCS was filled with TG for 2 min under the cover, at each of three locations; the cover remained closed during the TG saturation period. Directly afterward, the cover was opened and left open, the source of the TG was removed from the module at a distance of about 20 yd, and TG levels were recorded downstream by the Specific Vapor Analyzer (Miran) for 2 min. These recorded TG levels were subsequently used to approximate the contaminant removal rate from under various covers of the DBCS.
- Also, smoke was released under several access covers of the AFSM 100 to determine the time necessary for the LEV to evacuate the potential contaminants. Specifically, smoke was injected under the covers and the lids were immediately closed. Where the covers had windows, researchers were able to observe and record how long it took for the smoke to clear. Where the covers were opaque, they were opened after an amount of time corresponding to that needed for a worker to access them. The presence or absence of smoke under the covers was then observed and recorded.

Performance Criteria

In covered locations frequented by operators clearing jams or removing obstructions, possible contaminants needed to be captured quickly. Determining the recommended contaminant evacuation time was therefore governed by the amount of time necessary for the operator to reach the cover from the closest usual working position.

A more detailed description of the methods employed to evaluate mail-processing equipment by TG experimentation, smoke release observations, and air velocity measurements can be found in the NIOSH site visit report.⁽⁶⁾

RESULTS

Particle Count Experiments with Particulate Release

Variations in the data collected from experiments based on the introduction of anthrax spore-sized dust to the LEV were high enough that background noise in the data was at times greater than the generated signals. Figure 1, for example, shows that some experiments with the LEV control on (i.e., Experiments 11 and 12) had even higher spikes of particulate concentrations than for experiments with the LEV control off (i.e., Experiments 6–8). Confounding results like this made it apparent that this method did not lend itself to the evaluation of capture efficiencies in mail-processing facilities.

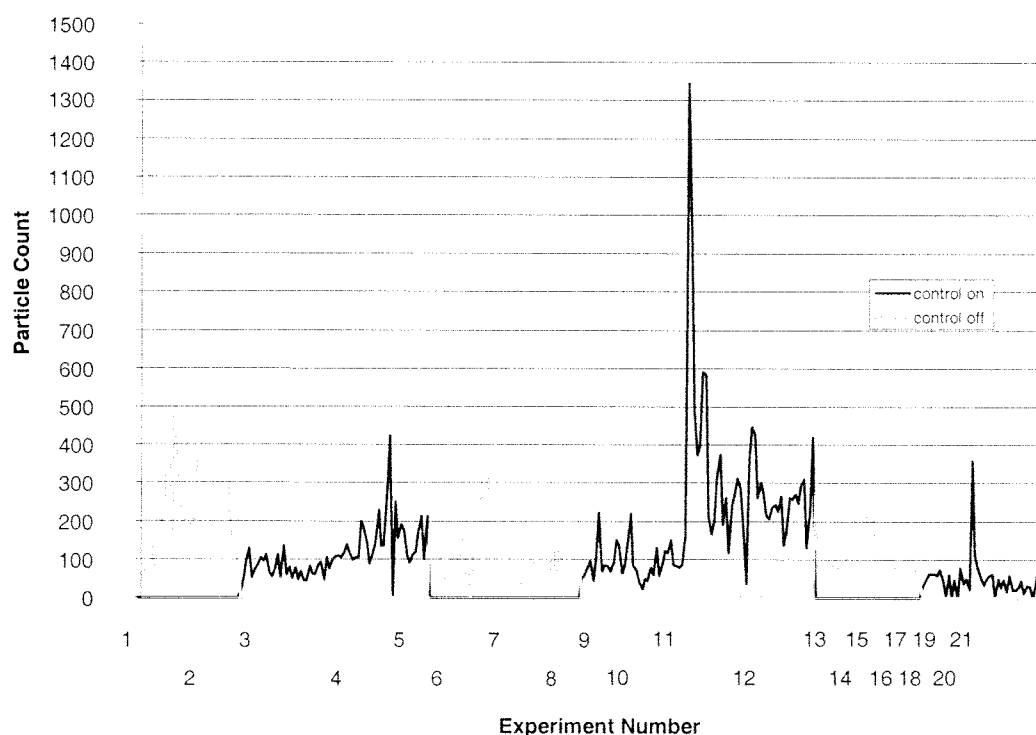


FIGURE 1. Particle count levels for particulate spiked mail. Dark values correspond to LEV-on particle levels for particles between 1 and 5 microns. Lighter values correspond to LEV-off particle levels for particles between 1 and 5 microns. The x-axis represents the experiment number. The data below is generated from measurements using an 1100 series particle size analyzer (Grimm Technologies) at the Delivery Bar Code Sorter.

Regular Mail Experiments

High particle concentrations measured as the background level in the postal facilities obscured specific determination of LEV effectiveness when compared with particle count levels collected during the processing of regular mail. For example, Figure 2 shows that regular mail experiments at the DBCS with the LEV on (i.e., Experiment 9) had even higher average levels of particulate than for experiments with the LEV off (i.e., Experiments 3 or 8). Such results were typical of this method and confounded clear evaluation of the capture efficiency of the system.

Air Velocity Measurements

Air velocity measurements were particularly useful in identifying potential areas of poor or marginal LEV performance; subsequent testing was then used to validate air velocity measurements. For instance, sample air velocity measurements made at the 010 Culling System (see Table I) showed that the left-hand loose mail distribution system (LMDS) hamper dump had capture velocities at the face of the hood curtain that were consistently lower than capture velocities in other, similar areas. The information led NIOSH investigators to pay particular attention to this area when making smoke release observations. Indeed, smoke release observations at the location later showed that a potential contaminant could have

TABLE I. Example of Air Velocity Values at Hamper Dump Locations of 010 Culling System

Area	Contaminant Capture Velocity (values of trials in fpm)
Left-hand DPRC hamper dump (at face of plastic curtain at various locations)	Trial 1: 121, 166, 138 Trial 2: 84, 151, 124
Right-hand DPRC hamper dump (at face of plastic curtain at various locations)	Trial 1: 153, 115 Trial 2: 102, 152, 119
Left-hand LMDS hamper dump (at face of plastic curtain at various locations)	Trial 1: 74, 87, 68 Trial 2: 61, 88, 83
Right-hand LMDS hamper dump (at face of plastic curtain at various locations)	Trial 1: 102, 92, 100 Trial 2: 74, 99, 97

Notes: All reported values are averages of three measurements taken at 2-sec intervals. The 010 culling system is made up of the dual pass rough culling system (DPRC) and loose mail distribution system (LMDS).

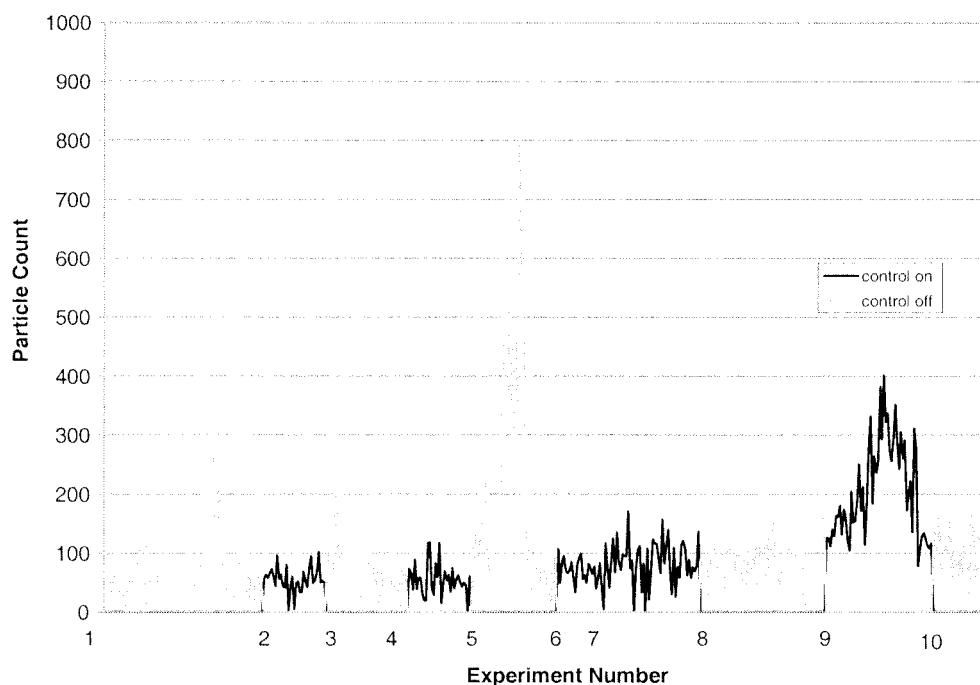


FIGURE 2. Particle count levels for regular mail. Dark values correspond to LEV-on particle levels for particles between 1 and 5 microns. Lighter values correspond to LEV-off particle levels for particles between 1 and 5 microns. The x-axis represents the experiment number. The data below is generated from measurements using an 1100 series particle size analyzer (Grimm Technologies) at the delivery bar code sorter.

been released through a gap in the opening of the hood, to the side of the exhaust slots. Presented with this information, the contractors agreed the gap should be closed to improve LEV performance.

Tracer Gas Evaluations

Tracer gas evaluations provided the most consistent method for obtaining quantifiable information about LEV systems. This was especially true because capture efficiency measured for the USPS LEV was consistently high, a result that made meaningful interpretation of the data clear and straightforward. Moreover, TG was relatively easy to set up and use in the field. However, the method's greatest benefit was its immunity to the large, variable quantities of particulate in the ambient air, a characteristic that made it particularly well suited for USPS mail-processing center evaluations. Table II shows TG capture efficiencies computed for locations at the 010 culling system. All capture efficiencies exceeded required values except for the area "Underneath Flats Ejector #1," where the TG capture efficiency was only about 28%. In this area the value was consistent with smoke release observations, which indicated poor contaminant capture potential. As a result of this specific information, the contractor agreed to modify the system to increase capture potential to meet system requirements.

Smoke Release Observations

The smoke release proved very effective not only for characterization of control effectiveness but also as an indication

of where other methods of evaluation, such as air velocity measurements and TG evaluations, should be concentrated. Moreover, smoke release was inexpensive and the required setup time was minimal. Figure 3 shows a NIOSH employee

TABLE II. Example of TG Capture Efficiencies at Potential Contaminant Release Points of 010 Culling System

Area	TG Capture Efficiency (%)
Left-hand DPRC hamper dump	>98
Right-hand DPRC hamper dump	>98
Left-hand DPRC waterfall area (bottom of letter drop)	>98
Right-hand DPRC waterfall area (bottom of letter drop)	>98
Sc-2 bypass at bottom of cart	>98
Sc-2 feed hood	97
Underneath flats ejector # 1 (unit with no capture enhancements)	28
Underneath flats ejector # 2 (unit with some rough capture enhancements made by USPS personnel)	>98

Note: The 010 culling system is made up of dual pass rough culling system (DPRC) and loose mail distribution system (LMDS).



FIGURE 3. NIOSH employee performing smoke release observations at LEV of United States Postal Service DBCS mail-processing equipment.

making smoke release observations. In this particular instance, the generated smoke was quickly and consistently entrained into the LEV at a potential contaminant release point.

Contaminant Removal Rate Determination

Experimental results from the monodisperse latex spheres to characterize contamination removal rates under the access hoods were marginalized by an inability to consistently generate aerosol clouds of similar sizes and by the high levels of background particulate. Although additional time spent in developing this method for characterization of contaminant removal rates might have yielded more consistent results, other methods proved better suited to the high-background particulate environment. For instance, because smoke release observations were particularly useful in qualitatively evaluating the effects of the LEV on potential contaminants under access covers, observations of smoke releases seemed a practical course. Tracer gas experiments for quantitatively depicting LEV effectiveness under the access covers were useful and better suited for the high background particulate environments than were particle count methods, despite some disadvantages: (1) processing data by this method was time and labor intensive, and (2) TG levels lowered slowly and asymptotically toward a significantly higher value than zero in several instances.

DISCUSSION

When using the preceding results to define the battery of tests recommended for the evaluation of capture effectiveness of LEV for mail-processing equipment, several considerations should be made:

- First, consistently high variability in values generated by the particle count experiments make interpretation of data difficult to impossible. The two main reasons for this variability are (1) the technology is lacking for introduction of large, repeatable, and precise amounts of particulate into equipment in the field, and (2) the amount of paper dust produced in USPS distribution centers is high and uncontrollable.
- Second, TG experiments seem to be an effective method for obtaining quantifiable data regarding LEV capture efficiency. The fundamental question answered by TG use is whether the LEV is effective at capturing aerosols of anthrax spore-sized particles (1–5 μm). Aerosol science validates the assumption that TG in many respects behaves like an aerosol of 1–5 microns, especially in locations where capture velocities are in excess of 100 fpm.⁽⁷⁾ Specifically, the settling velocity of 1- μm particles (3.5×10^{-5} m/sec or 6.9×10^{-3} fpm) and 5- μm particles (8×10^{-4} m/sec or .16 fpm) is easily overcome by the USPS-mandated capture velocities of 100 fpm, minimum, at locations of worker interface. Moreover, TG use is justified since the goal is to gain a good, overall picture of LEV capture effectiveness and not to describe the precise behavior of the particles inside the LEV. In addition, TG experiments are particularly useful since the ambient air, which has no TG, does not confound TG detection. Also, TG equipment is widely used and readily available to industrial hygienists for testing.

Tracer gas experiments used to characterize the behavior of a potential contaminant under access covers is potentially beneficial but also in need of further refinement before field

use. The fact that in several NIOSH evaluations TG levels dropped slowly and asymptotically toward a value significantly higher than zero indicated that the contaminant was being removed slowly from the entire LEV system but not necessarily from under the access cover of interest. Therefore, a redesign of this technique should not only give more accurate future results regarding the rate of contaminant removal under a specific access cover but also aid in understanding where contaminants could possibly accumulate in other parts of the system.

Finally, using several different methods in combination seems to be a good strategy for the evaluation of LEV capture efficiency in the field. For instance, smoke release observations serve as a sound basis for judging LEV effectiveness, but those observations need to be supported and quantified by TG evaluation. Likewise, detailed air velocity measurements mean little unless corroborated by data from TG and smoke release experiments. This is especially true since air velocity measurements are more an indicator of the accuracy of ventilation design and not an account of real-world conditions, whereas smoke release and TG observations are directly related to actual capture efficiency. Moreover, the order of testing can have a bearing on how many tests are necessary to characterize the system. For instance, conducting smoke release observations first, as is recommended, will influence the number and location of other tests and, thus, optimize experimental design.

CONCLUSIONS

Based on experimentation results described in the Methods, we found the following tools for evaluating contaminant capture efficiency of LEV effective for field use:

- Smoke release observations made at potential contaminant release points at or near workstations
- Air velocity measurements at potential contaminant release points in appropriate workstations
- TG measurements made at potential contaminant release points in or near workstations
- Smoke release observations to characterize the contaminant removal rate of contaminant from under access hoods.

Due to a variety of factors, our initial data collected from particle count experiments at the USPS were not consistent enough to estimate LEV capture potential. Although refined experimentation technique might obtain more consistent results, the TG method is better suited than particle counts in high background particulate environments, such as found in USPS processing and distribution centers.

RECOMMENDATIONS

The methods mentioned in the previous section were useful in characterizing the contaminant capture efficiency of LEV for USPS mail-processing equipment. These methods have been established as standard procedure for future NIOSH evaluations and will provide a framework for consistent and repeatable evaluations by the USPS and its contractors. Moreover, these methods could well serve as a basis for evaluating LEV on any bulk mail-processing equipment. For instance, government agencies—such as the Internal Revenue Service, Department of State, and Congress—or any private package or mail delivery company could benefit from adopting these methods. Furthermore, the methodology described here could be used to evaluate a wide variety of LEV systems: systems larger than laboratory hoods, systems in high background particulate environment, situations where the collection of personal samples might be difficult or impractical, or work areas where sampling directly for the contaminant of interest is difficult or not possible.

ACKNOWLEDGMENTS

The authors would like to thank the United States Postal Service for its partnership in developing procedures for evaluating USPS LEV. Most notably, Thomas Potter, Leung Shiu, and Marina Khazanov have been instrumental partners in this endeavor. The authors also wish to acknowledge the contributions of Mark Hoover, Andrew Maynard, Dave Marlow, Leroy Mickelsen, and Stanley Shulman of NIOSH, and to thank them for their help in conducting surveys.

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